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ANALYSIS OF VERTICAL-TAIL LOADS IN ROLLING PULL-OUT MANEUVERS

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ANALYSIS OF VERTICAL-TAIL LOADS IN ROLLING PULL-OUT MANEUVERS

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SUMMARY

An analysis is presented of the vertical-tail loads to be expected as a result of abrupt aileron action in accelerated flight, as in rolls from turns or pull-outs, for example.

The formulas derived show that the vertical-tail loads obtained in rolling pull-out maneuvers are directly proportional to the load factor, wing loading, and aileron effectiveness and are inversely proportional to directional stability. Sample calculations for an assumed fighter airplane are presented and discussed.

It appears that critical tail loads may occur in rolling pull-out maneuvers, particularly on airplanes with good ailerons and low directional stability.

INTRODUCTION

In fighter and dive-bomber airplanes, abrupt aileron action is frequently used in accelerated flight, as in rolls from turns or pull-outs, for example.

Because of the large yawing moments produced by ailerons in accelerated flight and because of the increase in aileron power achieved since the war, the vertical-tail loads obtainable in rolling pull-out maneuvers have been examined analytically and the factors on which the loads depend have been determined.

SYMBOLS

N yawing moment, foot-pounds

C_n yawing-moment coefficient

C_L	wing lift coefficient
p	rolling velocity, radians per second
b	wing span, feet
V	true airspeed, feet per second
$pb/2V$	helix angle generated by wing tip, radian
β	sideslip angle, degrees
$dC_n/d\beta$	airplane directional stability per degree
q	dynamic pressure, pounds per square foot
S_v	vertical-tail area, square feet
$dC_N/d\beta$	slope of tail normal-force-coefficient curve per degree
n	load factor, g
S	wing area, square feet
W	airplane gross weight, pounds
l_t	tail length, feet
L_v	load on vertical tail, pounds

DEVELOPMENT OF FORMULAS FOR DETERMINING VERTICAL-TAIL LOADS IN ROLLING PULL-OUTS

For elliptical span loading, the yawing moment due to aileron deflection and rolling velocity may be expressed with sufficient accuracy in terms of the wing lift coefficient and the helix angle in the roll as

$$C_n = \frac{C_L}{8} \frac{pb}{2V} \tag{1}$$

The sideslip angle β developed in the roll with rudder fixed is obtained, to a first approximation, by dividing the yawing-moment coefficient of equation (1) by the directional-stability coefficient of the airplane; thus,

$$\beta = \frac{C_n}{dC_n/d\beta}$$

$$= \frac{C_L}{8} \frac{pb}{2V} \frac{1}{dC_n/d\beta} \qquad (2)$$

The vertical-tail loads resulting from sideslip angles are the product of the sideslip angle, the vertical-tail area, the dynamic pressure, and the slope of the tail normal-force-coefficient curve; that is,

$$L_v = \beta S_v q \frac{dC_N}{d\beta} \qquad (3)$$

Since qC_L is equivalent to the product of wing loading and the load factor, equation (3) may be rewritten as

$$L_v = \frac{n}{8} \frac{W}{S} \frac{pb}{2V} S_v \frac{dC_N}{d\beta} \frac{1}{dC_n/d\beta} \qquad (4)$$

From equation (4) the vertical-tail load in a roll may be seen to increase in direct proportion to the load factor, the wing loading, and the aileron effectiveness. The loads are also proportional to the vertical-tail area and normal-force-coefficient slope and are inversely proportional to directional stability. Increasing the tail size and aspect ratio should, in general, reduce the loads because the directional stability increases faster than the product of area and normal-force-coefficient slope; that is, an increase in tail effectiveness should reduce the loads by restricting the sideslip angles and thereby reducing the unstable moments contributed by the fuselage and propeller. The loads represented by equation (4) would be chiefly loads on the fin due to angle of attack of the vertical tail.

If the rudder were sufficiently light per degree of deflection and rolls could be perfectly coordinated, the tail load would be

$$L_v = \frac{N}{l_t}$$

$$= \frac{n}{8} \frac{W}{S} \frac{pb}{2V} \frac{Sb}{l_t} \qquad (5)$$

This load would be primarily a rudder load and, in general, would be considerably smaller than that of equation (4) although the value of $pb/2V$ might be somewhat increased by the rolling moment due to yawing. It should be noted in addition, however, that with a light rudder the rudder could be applied after substantial sideslip had developed so that rudder loads would be added to the loads of equation (4).

CALCULATION OF TAIL LOADS FOR A TYPICAL FIGHTER AIRPLANE

In order to illustrate the order of magnitude of loads to be expected in rolling pull-out maneuvers, sample calculations are presented for a typical case. The assumed dimensions and characteristics of the airplane are as follows:

S, square feet	240
W/S, pounds per square foot	35
b, feet	38
S_v, square feet	26
$dC_N/d\beta$, per degree	0.045
$dC_n/d\beta$, per degree	-0.0005
l_t, feet	17

The variation with indicated airspeed of $pb/2V$ obtainable with a 50-pound stick force for the assumed airplane is shown in figure 1(a). The calculated angles of sideslip β produced as a result of rolling with a 50-pound stick force combined with normal accelerations of 3g and 6g are shown as a function of indicated airspeed in figure 1(b). The calculated loads on the vertical tail that result from the sideslip developed are shown in figure 1(c). The load on the tail with 6g normal acceleration and a 50-pound stick force, but with rudder used to maintain zero sideslip, is also shown in figure 1(c).

DISCUSSION

As may be seen from figure 1 or from formulas (1) to (5) from which figure 1 was constructed, large

vertical-tail loads may be produced by the aileron control. Although the loads are much lower when the rudder is used to maintain zero sideslip, rudder forces are, in general, far too heavy to permit use of the rudder except at relatively low speeds. Also to be considered is the case in which the rudder is applied after sideslip has developed so that the rudder action would tend to increase rather than to decrease the loads.

In the example shown in figure 1, the directional stability was assumed to be constant over the range of sideslip angle. In most actual cases, however, the yawing-moment-coefficient slope is small through a moderate range of sideslip angle and generally becomes great at larger angles. A small slope through neutral will cause the maximum tail loads to be produced at speeds higher than those shown in figure 1. In an actual case calculations would have to be made from the yawing-moment curve obtained from wind-tunnel tests made on a model on which a propeller having the proper side-force factor was installed.

Present methods of calculating the sideslip angles and therefore the loads resulting from aileron action are open to question. The approximate method presented herein is believed to give somewhat smaller sideslip angles than those actually obtained in flight and the sample loads presented are therefore probably too small.

CONCLUDING REMARKS

The analysis presented indicates that large and perhaps critical loads on the vertical tail will occur in rolling pull-outs. These loads are directly proportional to the load factor, wing loading, and aileron effectiveness and are inversely proportional to the directional stability of the airplane. More exact methods of calculating these loads are being developed.

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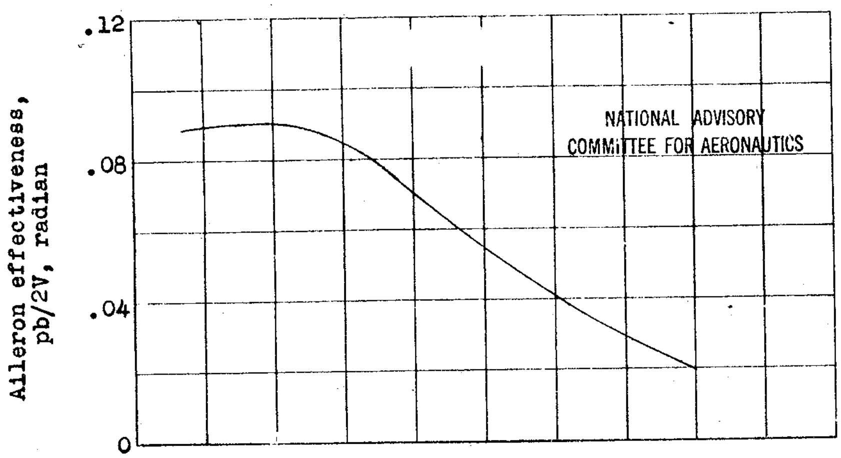
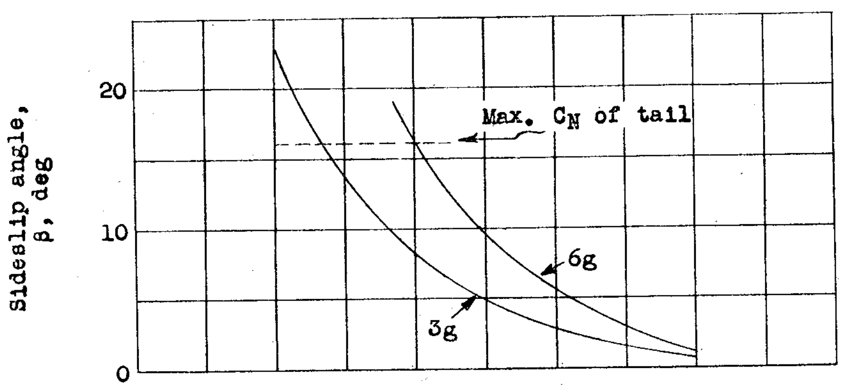
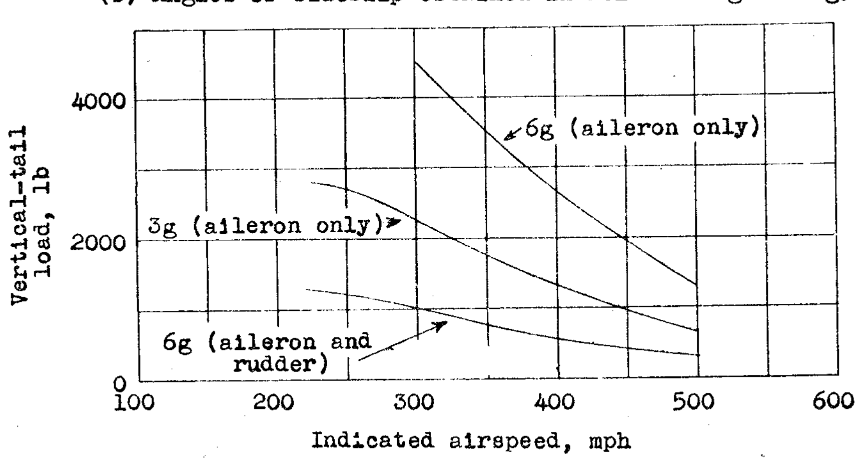


(a) Assumed values of pb/2V obtainable with 50-pound stick force.



(b) Angles of sideslip obtained in rolls at 3g and 6g.



(c) Vertical-tail loads at 3g and 6g in rolls using aileron only and at 6g using both aileron and rudder.

Figure 1.- Sample calculations of vertical-tail loads in rolling pull-out maneuvers.